Defense Technical Information Center Compilation Part Notice

This paper is a part of the following report:

- *Title:* Technology Showcase: Integrated Monitoring, Diagnostics and Failure Prevention. Proceedings of a Joint Conference, Mobile, Alabama, April 22-26, 1996.

- *To order the complete compilation report, use:* AD-A325 558

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

IN-LINE OIL DEBRIS MONITOR (ODM) FOR THE ADVANCED TACTICAL FIGHTER ENGINE

Dave Muir
GasTOPS Ltd.
1011 Polytek St.
Ottawa, Canada, K1J 9J3

Brad Howe
BFGoodrich Aerospace
Panton Road
Vergennes, VT 05491

Abstract: The development of an in-line, full flow oil debris sensor for the F119-PW-100 Advanced Tactical Fighter Engine is described. The sensor continuously counts and sizes wear metal particles, both ferrous and non-ferrous, in the main oil supply line of the engine. The design requirements, principle of operation, mechanical design features and electronic design features of the sensor are discussed. The performance characteristics of the sensor as measured during development testing are also presented.

Key Words: Advanced Tactical Fighter, F119 engine, F22 aircraft, in-line, oil debris sensor, wear metal detection.

INTRODUCTION: The Pratt and Whitney F119-PW-100 engine which powers the USAF Advanced Tactical Fighter (ATF) aircraft will be the first production military engine to incorporate an in-line, full flow oil debris detection capability in the lubrication system of the main engine bearings. This capability will be provided by an advanced technology Oil Debris Monitor (ODM) sensor system currently being developed by GasTOPS Ltd. for Pratt and Whitney. The ODM will be an integral component of the ATF Engine Monitoring System (EMS), which provides remote indication of the F119 engine sensor signals, comprehensive on-engine diagnostics and ground-based fault isolation using flight recorded data.

The ODM, shown in Figure 1, has successfully completed the pre-flight Engineering Test and Evaluation phase of the F119-PW-100 Full Scale Development Program. Initial Flight Release hardware is presently being provided to Pratt and Whitney for flight qualification testing. First flight of the ODM is planned for some time in 1997.

GasTOPS has also entered into a formal partnership agreement with BFGoodrich Aerospace for ongoing development and production of the ODM for aerospace applications.

This paper discusses the general requirement for in-line, full flow oil debris detection and summarizes the specific design requirements of the F119 ODM. The principles of operation of the ODM are described and a brief description of the sensor mechanical and electronic design features are provided. The results of bearing test rig experiments conducted by GasTOPS and Pratt and Whitney are also presented, demonstrating the capability of the ODM to monitor failure progression and characterize the quantity and nature of wear debris released during failure.

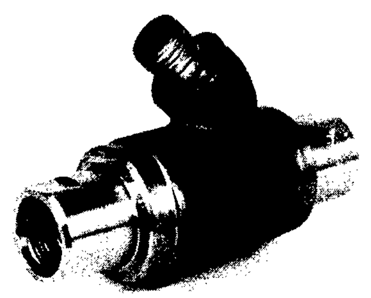

Figure 1 Oil Debris Monitor

REQUIREMENT: The main bearings of an aircraft engine operate under severe conditions of load, speed and temperature. Under these conditions, component damage can progress very rapidly from the point of an initial flaw to catastrophic failure; sometimes in a matter of only a few hours of operation. As well, main bearing failure frequently results in considerable secondary damage to the engine.

Some form of continuous monitoring is therefore required to detect the onset of failure and provide for safe shutdown of the engine. Magnetic chip detectors placed in the return oil flow line(s) from the bearings traditionally have been used for this purpose. These devices, however, rely on the oil-borne wear debris particles to make contact with the sensing element and remain trapped by its magnetic field. In conventional usage, the detection efficiency of a chip detector is quite poor. Moreover, chip detectors are not capable of detecting non-ferrous wear metal particles and are prone to false alarms due to the build up of fine ferrous debris.

The F119-PW-100 engine design provides for main engine bearing protection through the use of an inductive oil debris sensor which mounts directly onto the outlet of the main oil supply pump and provides continuous, in-line, full-flow wear metal debris detection. Typical performance requirements of the sensor include:

Debris Detection Size:	125 microns minimum
Debris Detection Efficiency:	100%
Debris Type:	ferrous and non-ferrous

The sensor must also meet the rigorous environmental requirements of an on-engine sensor including oil temperature (over 350°F), oil pressure (over 300 psia), entrained air (50% worst case), vibration and EMI requirements.

The output of the F119 ODM sensor will be fully integrated into the Engine Monitoring System (EMS) of the ATF. The EMS includes the Full Authority Digital Engine Control (FADEC) unit of each engine, a Comprehensive Engine Diagnostic Unit (CEDU) and the various sensors used for engine control and diagnostics. Processing of the ODM sensor signals is performed by the CEDU using electronic circuitry provided by GasTOPS.

SENSOR OPERATION: The ODM is a through flow device which installs in the main oil supply line and allows the entire oil flow to pass without obstruction. The sensor incorporates a magnetic coil assembly which is capable of detecting and categorizing wear metal particles by size and type (ferrous and conducting non-ferrous). The minimum detectable particle sizes are determined primarily by the inner diameter of the coil assembly. For the F119 application, these minimum sizes are approximately 125 microns for ferrous particles and 250 microns for non-ferrous particles.

The magnetic coil assembly consists of three coils which surround a magnetically inert section of tubing. The two outside field coils are driven by a high frequency alternating current source such that their respective fields are nominally opposed or cancel each other at a point inside the tube and just under the center sense coil. Disturbance of the magnetic fields caused by the passage of a particle results in a characteristic sense coil voltage as shown in Figure 2. The amplitude and phase of the output signature is used to identify the size and type of particle. The amplitude of the signal is proportional to the mass of the particle for ferrous materials and to the surface area of the particle for non-ferrous materials. The phase of the signal for non-ferrous particles is opposite to that of ferrous particles, allowing a distinction to be made between the two types of wear metal materials.

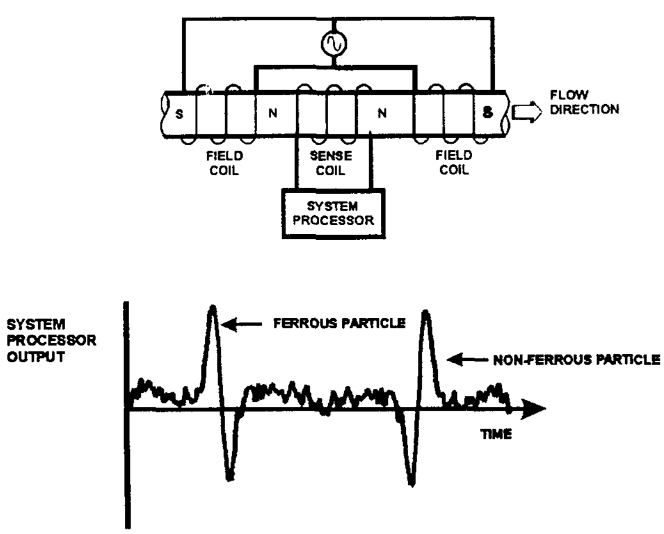

Figure 2 ODM System Operation

Signal conditioning using a threshold algorithm categorizes the particles that pass on the basis of size and type. Several size categories can be defined above the minimum particle size thresholds. Once a particle has been detected and its size determined, this information is stored in registers or bins which record the total number of particles of a given type and bin size that have been detected.

MECHANICAL DESIGN: The F119 ODM is installed on the housing of the lube oil pump. The oil enters the sensor through a 3 bolt flange connection and exits (approximately 8 inches away and rotated by 90°) through a piloted o-ring port.

To accommodate this installation the ODM was designed as a 2 piece unit including a sensor module (Figure 3) and elbow component. The sensor module contains the working elements of the sensor in a welded stainless steel housing designed to withstand the operating environment of the engine and to contain the oil under flame exposure. The unit is designed to minimize exposure of the coils to distortion due to external forces, vibration and oil pressure fluctuations. The elbow component of the sensor erves as an adapter to the oil pump. It accommodates the 90° rotated flange and allows for flexibility between the two components to accommodate mis-alignment between the sensor and pump. A spring, combined with the force of the oil pressure, keeps the sensor module held in place in the o-ring port during operation. A flexible ground strap and capture mechanism is used to provide the necessary electrical bonding to the engine structure and keep the two sensor components together during installation and removal.

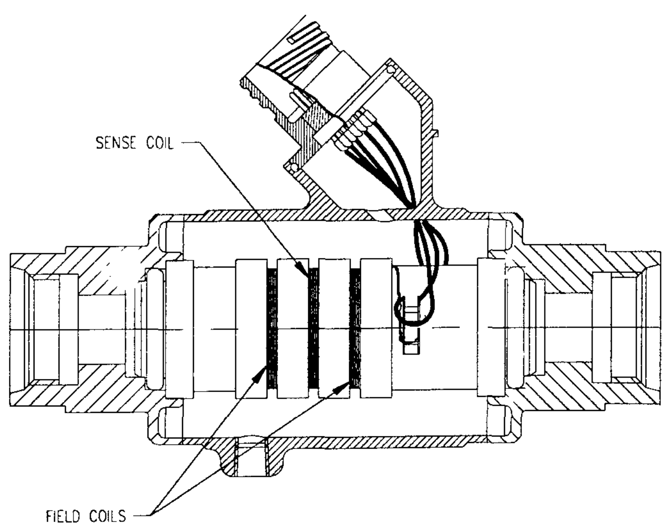

Figure 3 ODM Sensor Module

ELECTRONIC DESIGN: The ODM sensor signals are processed by electronics located in the Comprehensive Engine Diagnostic Unit (CEDU). The design that is currently undergoing Initial Flight Release testing includes two semi-custom integrated circuits which perform the analog and digital ODM processing functions. The analog functions are performed by an Application-Specific Integrated Circuit (ASIC) designed by GasTOPS and built by Harris Semiconductor. The ASIC includes electronics to amplify and filter the sensor signals, remove the residual sensor imbalance signal, and extract and detect particle signatures. The digital circuit, a Field-Programmable Gate Array (FPGA), processes the signature outputs, determines the type of particle detected (ferrous/non-ferrous), records particle counts, and interfaces with the CEDU microprocessor. The two integrated circuits also work together to provide comprehensive Built-In Test (BIT) functions which provide both fault detection and isolation.

The electronics design is being improved for the Initial Service Release version of the F119 ODM. Some of the particle detection functions are being moved into a Digital Signal Processor already present in the CEDU. This change will both simplify the hardware and provide enhanced particle sizing capability.

BEARING TEST PROGRAM: In order to establish reliable criterion for warning, alarm or shutdown conditions based on the ODM output readings, a test program has been undertaken to investigate the failure of aircraft engine bearings. The goal of this program is to quantify the debris released from bearings during failure and to evaluate the capability of the ODM to monitor failure progression. The program involves the running of bearings past the point of normally accepted failure and monitoring the debris released from the bearings as the failures progress.

Small Scale Bearing Tests: A large number of steel (i.e. ferrous) bearings (over 40 in total) have been run to failure in a test rig specially designed and instrumented for small scale (2 inch diameter) ball and roller bearings tests, as shown in Figure 4. The rig incorporates a fine mesh screen which captures the debris released during each failure for subsequent comparison to the ODM readings.

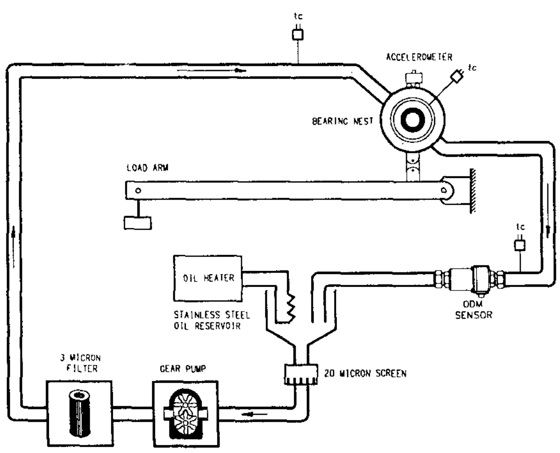

Figure 4 Bearing Test Rig

Detailed results of these tests have been presented in an earlier publication [1]. As illstrated in Figures 5 and 6, both the sensor measurements and the findings of the filter debris analysis verify that large numbers of wear metal particles within the detectable size range of the sensor are released; starting with the first spall, continuing as the bearing is kept in operation and increasing in rate as damage reaches an advanced state.

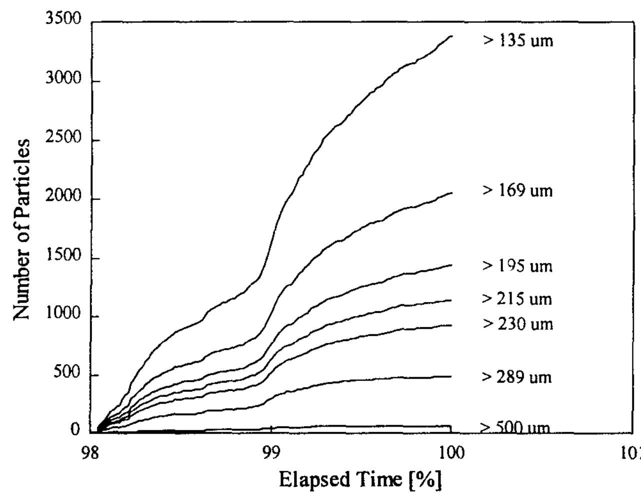

Figure 5 Sensor Output During Bearing Test

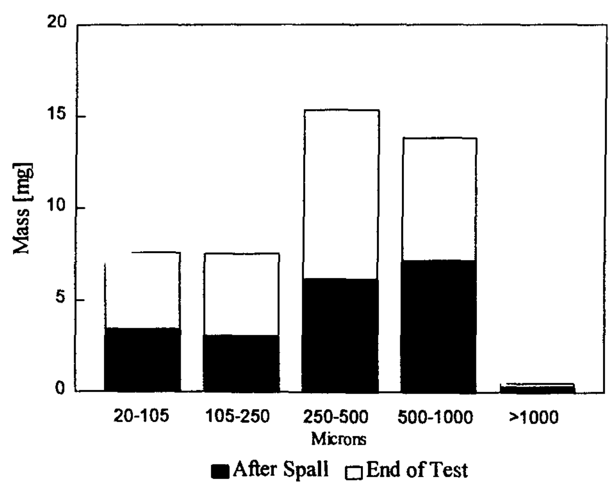

Figure 6 Filter Backwash Results

It has been established from these tests that the severity of the damage can be correlated to the mass of the wear metal material removed from the bearing contact surfaces, as shown in Figure 7. This suggests that reliable caution and alarm thresholds can be established based on the cumulative mass of debris measured by the ODM.

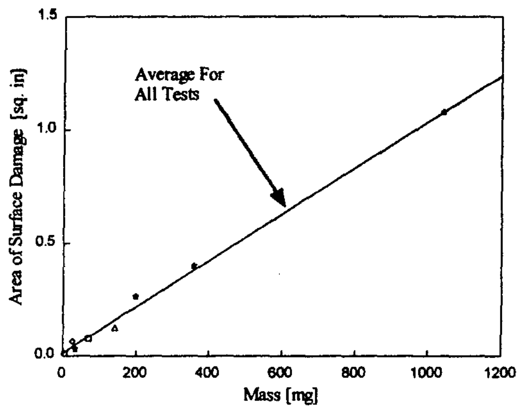

Figure 7 Correlation Between Sensor Output (Mass) and Observed Surface Damage

A single test has been conducted by Pratt and Whitney on a large diameter thrust bearing from an aircraft engine application. The bearing material was steel and failure was initiated by intentionally damaging each of the functional surfaces of the bearing (inner race, outer race and balls) using 0.025 inch diameter indents. The rig was operated at maximum bearing load conditions until vibration levels reached approximately 50 g's, at which time the rig was shut down and the bearing inspected. Inspection of the bearing following the test revealed extensive inner race spalling, outer race distress, ball spalling and flaking and cage fracture.

Figure 8 shows the number of particles generated above each of the ferrous particle thresholds used for the test. As indicated, the sensor detected the initial spall and counted significant numbers of wear metal particles greater than 200 microns throughout the failure. In total, over 150,000 ferrous particles greater than 200 microns and more than 25,000 particles larger than 700 microns were counted. Also of note was the rapid increase in the rate of particles counted during the latter portion of the test.

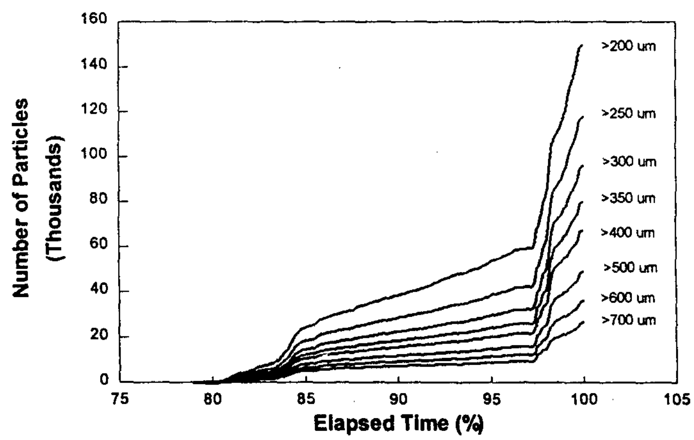

Figure 8 Large Scale Bearing Test Results

Hybrid Bearing Test: A single test has also been conducted on an advanced technology hybrid bearing for aircraft engine application. Failure of this bearing, which incorporated ceramic balls and steel races, was initiated by a series of 0.02 inch diameter stress concentration pits created on the inner race of the bearing. The bearing was run progressively from the point of initial spall to a point at which severe spalling damage was evident over roughly 10% of the race circumference.

Figure 9 shows the number of ferrous particles generated above each of the size thresholds used for the test. Once again, over the course of the test a loop number of wear metal particles were counted by the sensor (over 7,000 particles greater than 200 microns and over 100 particles greater than 700 microns). As in the case of the large scale bearing test, a significant increase in the rate of particles counted during the latter stages of the failure was evident.

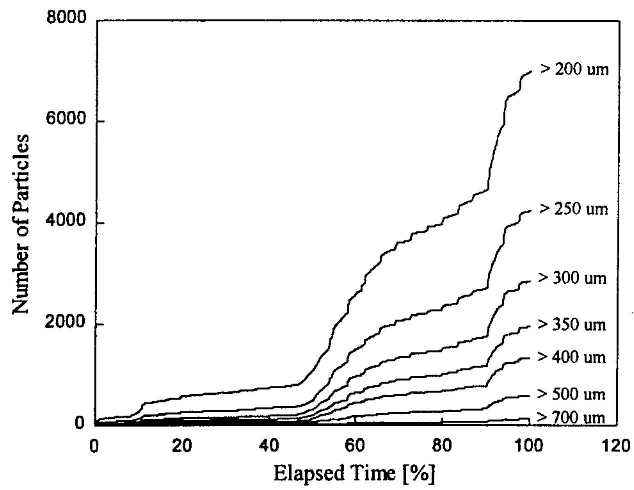

Figure 9 Hybrid Bearing Test Results

SUMMARY: An in-line full flow Oil Debris Monitor has been developed for the F119-PW-100 Advanced Tactical Fighter Engine and is presently undergoing flight qualification testing. The ODM is based on an advanced inductive sensing technology which is capable of detecting both ferrous and non-ferrous wear metal particles under full flow conditions. The ODM is fully integrated into the design of the F119 engine. The mechanical elements of the system are incorporated into the design of the engine's oil supply pump and the signal processing circuitry is fully integrated into the engine's Comprehensive Engine Diagnostic Unit. Bearing failure progression testing conducted by GasTOPS and Pratt and Whitney has verified that the ODM is capable of detecting the initiation of bearing damage and monitoring the progression of this damage towards failure.

REFERENCE:

[1] I. Hughes and D. Muir,
"On-Line Oil Debris Monitor For Aircraft Engines",
JOAP Conference, November, 1994.